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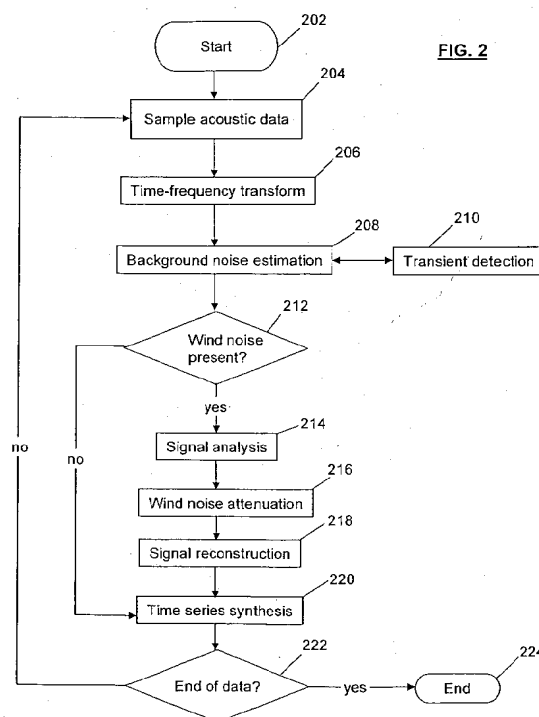
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(54) **System for suppressing wind noise**

(57) The invention includes a method, apparatus, and computer program to selectively suppress wind noise while preserving narrow-band signals in acoustic data. Sound from one or several microphones is digitized into binary data. A time-frequency transform is applied to the data to produce a series of spectra. The spectra are analyzed to detect the presence of wind noise and narrow band signals. Wind noise is selectively suppressed while preserving the narrow band signals. The narrow band signal is interpolated through the times and frequencies when it is masked by the wind noise. A time series is then synthesized from the signal spectral estimate that can be listened to. This invention overcomes prior art limitations that require more than one microphone and an independent measurement of wind speed. Its application results in good-quality speech from data severely degraded by wind noise.



Description

RELATED APPLICATION

5 [0001] This application claims the benefit of United States Provisional Patent Application No. 60/449,511, filed February 21, 2003.

BACKGROUND OF THE INVENTION

10 **1. Field of the Invention**

[0002] The present invention relates to the field of acoustics, and in particular to a method and apparatus for suppressing wind noise.

15 **2. Description of Related Art**

[0003] When using a microphone in the presence of wind or strong airflow, or when the breath of the speaker hits a microphone directly, a distinct impulsive low-frequency puffing sound can be induced by wind pressure fluctuations at the microphone. This puffing sound can severely degrade the quality of an acoustic signal. Most solutions to this problem involve the use of a physical barrier to the wind, such as fairing, open cell foam, or a shell around the microphone. Such a physical barrier is not always practical or feasible. The physical barrier methods also fail at high wind speed. For this reason, prior art contains methods to electronically suppress wind noise.

20 [0004] For example, Shust and Rogers in "Electronic Removal of Outdoor Microphone Wind Noise" -Acoustical Society of America 136th meeting held October 13th, 1998 in Norfolk, VA. Paper 2pSPb3, presented a method that measures the local wind velocity using a hot-wire anemometer to predict the wind noise level at a nearby microphone. The need for a hot-wire anemometer limits the application of that invention. Two patents, U.S. Pat. No. 5,568,559 issued Oct. 22, 1996, and U.S. Pat. No. 5,146,539 issued Dec. 23, 1997, both require that two microphones be used to make the recordings and cannot be used in the common case of a single microphone.

25 [0005] These prior art inventions require the use of special hardware, severely limiting their applicability and increasing their cost. Thus, it would be advantageous to analyze acoustic data and selectively suppress wind noise, when it is present, while preserving signal without the need for special hardware.

SUMMARY OF THE INVENTION

35 [0006] The invention includes a method, apparatus, and computer program to suppress wind noise in acoustic data by analysis-synthesis. The input signal may represent human speech, but it should be recognized that the invention could be used to enhance any type of narrow band acoustic data, such as music or machinery. The data may come from a single microphone, but it could as well be the output of combining several microphones into a single processed channel, a process known as "beamforming". The invention also provides a method to take advantage of the additional information available when several microphones are employed.

40 [0007] The preferred embodiment of the invention attenuates wind noise in acoustic data as follows. Sound input from a microphone is digitized into binary data. Then, a time-frequency transform (such as short-time Fourier transform) is applied to the data to produce a series of frequency spectra. After that, the frequency spectra are analyzed to detect the presence of wind noise and narrow-band signal, such as voice, music, or machinery. When wind noise is detected, it is selectively suppressed. Then, in places where the signal is masked by the wind noise, the signal is reconstructed by extrapolation to the times and frequencies. Finally, a time series that can be listened to is synthesized. In another embodiment of the invention, the system suppresses all low frequency wide-band noise after having performed a time-frequency transform, and then synthesizes the signal.

45 [0008] The invention has the following advantages: no special hardware is required apart from the computer that is performing the analysis. Data from a single microphone is necessary but it can also be applied when several microphones are available. The resulting time series is pleasant to listen to because the loud wind puffing noise has been replaced by near-constant low-level noise and signal.

50 [0009] The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] For a more complete description of the present invention and further aspects and advantages thereof, reference is now made to the following drawings in which:

Fig. 1 is a block diagram of a programmable computer system suitable for implementing the wind noise attenuation method of the invention.

Fig. 2 is a flow diagram of the preferred embodiment of the invention.

Fig. 3 illustrates the basic principles of signal analysis for a single channel of acoustic data.

Fig. 4 illustrates the basic principles of signal analysis for multiple microphones.

Fig. 5A is a flow diagram showing the operation of signal analyzer.

Fig. 5B is a flow diagram showing how the signal features are used in signal analysis according to one embodiment of the present invention.

Fig. 6A illustrates the basic principles of wind noise detection.

Fig. 6B is a flow chart showing the steps involved in wind noise detection.

Fig. 7 illustrates the basic principles of wind noise attenuation.

DETAILED DESCRIPTION OF THE INVENTION

[0011] A method, apparatus and computer program for suppressing wind noise is described. In the following description, numerous specific details are set forth in order to provide a more detailed description of the invention. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without these specific details. In other instances, well known details have not been provided so as to not obscure the invention.

Overview of Operating Environment

[0012] Fig. 1 shows a block diagram of a programmable processing system which may be used for implementing the wind noise attenuation system of the invention. An acoustic signal is received at a number of transducer microphones 10, of which there may be as few as a single one. The transducer microphones generate a corresponding electrical signal representation of the acoustic signal. The signals from the transducer microphones 10 are then preferably amplified by associated amplifiers 12 before being digitized by an analog-to-digital converter 14. The output of the analog-to-digital converter 14 is applied to a processing system 16, which applies the wind attenuation method of the invention. The processing system may include a CPU 18, ROM 20, RAM 22 (which may be writable, such as a flash ROM), and an optional storage device 26, such as a magnetic disk, coupled by a CPU bus 24 as shown.

[0013] The output of the enhancement process can be applied to other processing systems, such as a voice recognition system, or saved to a file, or played back for the benefit of a human listener. Playback is typically accomplished by converting the processed digital output stream into an analog signal by means of a digital-to-analog converter 28, and amplifying the analog signal with an output amplifier 30 which drives an audio speaker 32 (e.g., a loudspeaker, headphone, or earphone).

Functional Overview of System

[0014] One embodiment of the wind noise suppression system of the present invention is comprised of the following components. These components can be implemented in the signal processing system as described in Fig. 1 as processing software, hardware processor or a combination of both. Fig. 2 describes how these components work together to perform the task wind noise suppression.

[0015] A first functional component of the invention is a time-frequency transform of the time series signal.

[0016] A second functional component of the invention is background noise estimation, which provides a means of estimating continuous or slowly varying background noise. The dynamic background noise estimation estimates the continuous background noise alone. In the preferred embodiment, a power detector acts in each of multiple frequency bands. Noise-only portions of the data are used to generate the mean of the noise in decibels (dB).

[0017] The dynamic background noise estimation works closely with a third functional component, transient detection. Preferably, when the power exceeds the mean by more than a specified number of decibels in a frequency band (typically 6 to 12 dB), the corresponding time period is flagged as containing a transient and is not used to estimate the continuous background noise spectrum.

[0018] The fourth functional component is a wind noise detector. It looks for patterns typical of wind buffets in the spectral domain and how these change with time. This component helps decide whether to apply the following steps. If no wind buffeting is detected, then the following components can be optionally omitted.

[0019] A fifth functional component is signal analysis, which discriminates between signal and noise and tags signal for its preservation and restoration later on.

[0020] The sixth functional component is the wind noise attenuation. This component selectively attenuates the portions of the spectrum that were found to be dominated by wind noise, and reconstructs the signal, if any, that was masked by the wind noise.

[0021] The seventh functional component is a time series synthesis. An output signal is synthesized that can be listened to by humans or machines.

[0022] A more detailed description of these components is given in conjunction with Figs. 2 through 7.

Wind Suppression Overview

[0023] Fig. 2 is a flow diagram showing how the components are used in the invention. The method shown in Fig. 2 is used for enhancing an incoming acoustic signal corrupted by wind noise, which consists of a plurality of data samples generated as output from the analog-to-digital converter 14 shown in Fig. 1. The method begins at a Start state (step 202). The incoming data stream (e.g., a previously generated acoustic data file or a digitized live acoustic signal) is read into a computer memory as a set of samples (step 204). In the preferred embodiment, the invention normally would be applied to enhance a "moving window" of data representing portions of a continuous acoustic data stream, such that the entire data stream is processed. Generally, an acoustic data stream to be enhanced is represented as a series of data "buffers" of fixed length, regardless of the duration of the original acoustic data stream. In the preferred embodiment, the length of the buffer is 512 data points when it is sampled at 8 or 11 kHz. The length of the data point scales in proportion of the sampling rate.

[0024] The samples of a current window are subjected to a time-frequency transformation, which may include appropriate conditioning operations, such as pre-filtering, shading, *etc.* (206). Any of several time-frequency transformations can be used, such as the short-time Fourier transform, bank of filter analysis, discrete wavelet transform, *etc.* The result of the time-frequency transformation is that the initial time series $x(t)$ is transformed into transformed data. Transformed data comprises a time-frequency representation $X(f, i)$, where t is the sampling index to the time series x , and f and i are discrete variables respectively indexing the frequency and time dimensions of X . The two-dimensional array $X(f, i)$ as a function of time and frequency will be referred to as the "spectrogram" from now on. The power levels in individual bands f are then subjected to background noise estimation (step 208) coupled with transient detection (step 210). Transient detection looks for the presence of transient signals buried in stationary noise and determines estimated starting and ending times for such transients. Transients can be instances of the sought signal, but can also be "puffs" induced by wind, i.e. instance of wind noise, or any other impulsive noise. The background noise estimation updates the estimate of the background noise parameters between transients. Because background noise is defined as the continuous part of the noise, and transients as anything that is not continuous, the two needed to be separated in order for each to be measured. That is why the background estimation must work in tandem with the transient detection.

[0025] An embodiment for performing background noise estimation comprises a power detector that averages the acoustic power in a sliding window for each frequency band f . When the power within a predetermined number of frequency bands exceeds a threshold determined as a certain number c of decibels above the background noise, the power detector declares the presence of a transient, i.e., when:

$$X(f, i) > B(f) + c, \quad (1)$$

where $B(f)$ is the mean background noise power in band f and c is the threshold value. $B(f)$ is the background noise estimate that is being determined.

[0026] Once a transient signal is detected, background noise tracking is suspended. This needs to happen so that transient signals do not contaminate the background noise estimation process. When the power decreases back below the threshold, then the tracking of background noise is resumed. The threshold value c is obtained, in one embodiment, by measuring a few initial buffers of signal assuming that there are no transients in them. In one embodiment, c is set to a range between 6 and 12 dB. In an alternative embodiment, noise estimation need not be dynamic, but could be measured once (for example, during boot-up of a computer running software implementing the invention), or not necessarily frequency dependent.

[0027] Next, in step 212, the spectrogram X is scanned for the presence of wind noise. This is done by looking for spectral patterns typical of wind noise and how these change with time. This components help decide whether to apply the following steps. If no wind noise is detected, then the steps 214, 216, and 218 can be omitted and the process skips to step 220.

[0028] If wind noise is detected, the transformed data that has triggered the transient detector is then applied to a

signal analysis function (step 214). This step detects and marks the signal of interest, allowing the system to subsequently preserve the signal of interest while attenuating wind noise. For example, if speech is the signal of interest, a voice detector is applied in step 214. This step is described in more details in the section titled "Signal Analysis."

[0029] Next, a low-noise spectrogram C is generated by selectively attenuating X at frequencies dominated by wind noise (step 216). This component selectively attenuates the portions of the spectrum that were found to be dominated by wind noise while preserving those portions of the spectrum that were found to be dominated by signal. The next step, signal reconstruction (step 218), reconstructs the signal, if any, that was masked by the wind noise by interpolating or extrapolating the signal components that were detected in periods between the wind buffets. A more detailed description of the wind noise attenuation and signal reconstruction steps are given in the section titled "Wind Noise Attenuation and Signal Reconstruction."

[0030] In step 220, a low-noise output time series y is synthesized. The time series y is suitable for listening by either humans or an Automated Speech Recognition system. In the preferred embodiment, the time series is synthesized through an inverse Fourier transform.

[0031] In step 222, it is determined if any of the input data remains to be processed. If so, the entire process is repeated on a next sample of acoustic data (step 204). Otherwise, processing ends (step 224). The final output is a time series where the wind noise has been attenuated while preserving the narrow band signal.

[0032] The order of some of the components may be reversed or even omitted and still be covered by the present invention. For example, in some embodiment the wind noise detector could be performed before background noise estimation, or even omitted entirely.

signal Analysis

[0033] The preferred embodiment of signal analysis makes use of at least three different features for distinguish narrow band signal from wind noise in a single channel (microphone) system. An additional fourth feature can be used when more than one microphone is available. The result of using these features is then combined to make a detection decision. The features comprise:

- 1) the peaks in the spectrum of narrow band signals are harmonically related, unlike those of wind noise
- 2) their frequencies are narrower those of wind noise,
- 3) they last for longer periods of time than wind noise,
- 4) the rate of change of their positions and amplitudes are less drastic than that of wind noise, and
- 5) (multi-microphone only) they are more strongly correlated among microphones than wind noise.

[0034] The signal analysis (performed in step 214) of the present invention takes advantage of the quasi-periodic nature of the signal of interest to distinguish from non-periodic wind noises. This is accomplished by recognizing that a variety of quasi-periodic acoustical waveforms including speech, music, and motor noise, can be represented as a sum of slowly-time-varying amplitude, frequency and phase modulated sinusoids waves:

$$s(n) = \sum_{k=1}^K A_k \cos(2\pi n k f_0 + \psi_k) \quad (2)$$

in which the sine-wave frequencies are multiples of the fundamental frequency f_0 and $A_k(n)$ is the time-varying amplitude for each component.

[0035] The spectrum of a quasi-periodic signal such as voice has finite peaks at corresponding harmonic frequencies. Furthermore, all peaks are equally distributed in the frequency band and the distance between any two adjacent peaks is determined by the fundamental frequency.

[0036] In contrast to quasi-periodic signal, noise-like signals, such as wind noise, have no clear harmonic structure. Their frequencies and phases are random and vary within a short time. As a result, the spectrum of wind noise has peaks that are irregularly spaced.

[0037] Besides looking at the harmonic nature of the peaks, three other features are used. First, in most case, the peaks of wind noise spectrum in low frequency band are wider than the peaks in the spectrum of the narrow band signal, due to the overlapping effect of close frequency components of the noise. Second, the distance between adjacent peaks of the wind noise spectra is also inconsistent (non-constant). Finally, another feature that is used to detect narrow band signals is their relative temporal stability. The spectra of narrow band signals generally change slower than that of wind noise. The rate of change of the peaks positions and amplitudes are therefore also used as features to discriminate between wind noise and signal.

Examples of Signal Analysis

[0038] Fig. 3 illustrates some of the basic spectral features that are used in the present invention to discriminate between wind noise and the signal of interest when only a single channel is present. The approach taken here is based on heuristic. In particular, it is based on the observation that when looking at the spectrogram of voiced speech or sustained music, a number of narrow peaks 302 can usually be detected. On the other hand, when looking at the spectrogram of wind noise, the peaks 304 are broader than those of speech 302. The present invention measures the width of each peak and the distance between adjacent peaks of the spectrogram and classifies them into possible wind noise peaks or possible harmonic peaks according to their patterns. Thus the distinction between wind noise and signal of interest can be made.

[0039] Fig. 4 is an example signal diagram that illustrates some of the basic spectral features that are used in the present invention to discriminate between wind noise and the signal of interest when more than one microphone are available. The solid line denotes the signal from one microphone and the dotted line denoted the signal from another nearby microphone.

[0040] When there are more than one microphone present, the method uses an additional feature to distinguish wind noise in addition to the heuristic rules described in Fig. 3. The feature is based on observation that, depending on the separation between the microphones, certain maximum phase and amplitude difference are expected for acoustic signals (i.e. the signal is highly correlated between the microphones). In contrast, since wind noise is generated from chaotic pressure fluctuations at the microphone membranes, the pressure variations it generates are uncorrelated between the microphones. Therefore, if the phase and amplitude differences between spectral peaks 402 and the corresponding spectrum 404 from the other microphone exceed certain threshold values, the corresponding peaks are almost certainly due to wind noise. The differences can thus be labeled for attenuation. Conversely, if the phase and amplitude differences between spectral peaks 406 and the corresponding spectrum 404 from the other microphone is below certain threshold values, then the corresponding peaks are almost certainly due to acoustic signal. The differences can be thus labeled for preservation and restoration.

Signal Analysis Implementation

[0041] Fig. 5A is a flow chart that shows how the narrow band signal detector analyzes the signal. In step 504, various characteristics of the spectrum are analyzed. Then in step 506, an evidence weight is assigned based on the analysis on each signal feature. Finally in step 508, all the evidence weights are processed to determine whether signal has wind noise.

[0042] In one embodiment, any one of the following features can be used alone or in any combination thereof to accomplish step 504:

- 1) finding all peaks in spectra having $SNR > T$
- 2) measuring peak width as a way to determine whether the peaks are stemming from wind noise
- 3) measuring the harmonic relationship between peaks
- 4) comparing peaks in spectra of the current buffer to the spectra from the previous buffer
- 5) comparing peaks in spectra from different microphones (if more than one microphone is used).

[0043] Fig. 5B is a flow chart that shows how the narrow band signal detector uses various features to distinguish narrow band signals from wind noise in one embodiment. The detector begins at a Start state (step 512) and detects all peaks in the spectra in step 514. All peaks in the spectra having Signal-to-Noise Ratio (SNR) over a certain threshold T are tagged. Then in step 516, the width of the peaks is measured. In one embodiment, this is accomplished by taking the average difference between the highest point and its neighboring points on each side. Strictly speaking, this method measures the height of the peaks. But since height and width are related, measuring the height of the peaks will yield a more efficient analysis of the width of the peaks. In another embodiment, the algorithm for measuring width is as follows:

Given a point of the spectrum $s(i)$ at the i th frequency bin, it is considered a peak if and only if:

$$s(i) > s(i-1) \quad (3)$$

and

$$s(i) > s(i+1). \quad (4)$$

Furthermore, a peak is classified as being voice (i.e. signal of interest) if:

$$s(i) > s(i-2) + 7\text{dB} \quad (5)$$

and

$$s(i) > s(i+2) + 7\text{dB}. \quad (6)$$

Otherwise the peak is classified as noise (e.g. wind noise). The numbers shown in the equation (e.g. $i-2$, 7dB) are just in this one example embodiment and can be modified in other embodiments. Note that the peak is classified as a peak stemming from signal of interest when it is sharply higher than the neighboring points (equations 5 and 6). This is consistent with the example shown in Fig. 3, where peaks 302 from signal of interest are sharp and narrow. In contrast, peaks 304 from wind noise are wide and not as sharp. The algorithm above can distinguish the difference.

[0044] Following along again in Fig. 5, in step 518 the harmonic relationship between peaks is measured. The measurement between peaks is preferably implemented through applying the direct cosine transform (DCT) to the amplitude spectrogram $X(f, i)$ along the frequency axis, normalized by the first value of the DCT transform. If voice (i.e. signal of interest) dominates during at least some region of the frequency domain, then the normalized DCT of the spectrum will exhibit a maximum at the value of the pitch period corresponding to acoustic data (e.g. voice). The advantage of this voice detection method is that it is robust to noise interference over large portions of the spectrum. This is because, for the normalized DCT to be high, there must be good SNR over portions of the spectrum.

[0045] In step 520, the stability of the peaks in narrow band signals is then measured. This step compares the frequency of the peaks in the previous spectra to that of the present one. Peaks that are stable from buffer to buffer receive added evidence that they belong to an acoustic source and not to wind noise.

[0046] Finally, in step 522, if signals from more than one microphone are available, the phase and amplitudes of the spectra at their respective peaks are compared. Peaks whose amplitude or phase differences exceed certain threshold are considered to belong to wind noise. On the other hand, peaks whose amplitude or phase differences come under certain thresholds are considered to belong to an acoustic signal. The evidence from these different steps are combined in step 524, preferably by a fuzzy classifier, or an artificial neural network, giving the likelihood that a given peak belong to either signal or wind noise. Signal analysis ends at step 526.

Wind Noise Detection

[0047] Fig. 6A and 6B illustrate the principles of wind noise detection (step 212 of Fig. 2). As illustrated in Fig. 6A, the spectrum of wind noise 602 (dotted line) has, in average, a constant negative slope across frequency (when measured in dB) until it reaches the value of the continuous background noise 604. Fig. 6B shows the process of wind noise detection. In the preferred embodiment, in step 652, the presence of wind noise is detected by first fitting a straight line 606 to the low-frequency portion 602 of the spectrum (e.g. below 500 Hz). The values of the slope and intersection point are then compared to some threshold values in step 654. If they are found to both pass that threshold, the buffer is declared to contain wind noise in step 656. If not, then the buffer is not declared to contain any wind noise (step 658).

Wind Noise Attenuation and Signal Reconstruction

[0048] Fig. 7 illustrates an embodiment of the present invention to selectively attenuate wind noise while preserving and reconstructing the signal of interest. Peaks that are deemed to be caused by wind noise (702) by signal analysis step 214 are attenuated. On the other hand peaks that are deemed to be from the signal of interest (704) are preserved. The value to which the wind noise is attenuated is the greatest of the follow two values: (1) that of the continuous background noise (706) that was measured by the background noise estimator (step 208 of Fig. 2), or (2) the extrapolated value of the signal (708) whose characteristics were determined by the signal analysis (step 214 of Fig. 2). The output of the wind noise attenuator is a spectrogram (710) that is consistent with the measured continuous background noise and signal, but that is devoid of wind noise.

Computer Implementation

[0049] The invention may be implemented in hardware or software, or a combination of both (e.g., programmable logic arrays). Unless otherwise specified, the algorithms included as part of the invention are not inherently related to any particular computer or other apparatus. In particular, various general-purpose machines may be used with programs written in accordance with the teachings herein, or it may be more convenient to construct more specialized apparatus to perform the required method steps. However, preferably, the invention is implemented in one or more computer programs executing on programmable systems each comprising at least one processor, at least one data storage system (including volatile and non-volatile memory and/or storage elements), and at least one microphone input. The program code is executed on the processors to perform the functions described herein.

[0050] Each such program may be implemented in any desired computer language (including machine, assembly, high level procedural, or object oriented programming languages) to communicate with a computer system. In any case, the language may be a compiled or interpreted language.

[0051] Each such computer program is preferably stored on a storage media or device (e.g., solid state, magnetic or optical media) readable by a general or special purpose programmable computer, for configuring and operating the computer when the storage media or device is read by the computer to perform the procedures described herein. For example, the compute program can be stored in storage 26 of Fig. 1 and executed in CPU 18. The present invention may also be considered to be implemented as a computer-readable storage medium, configured with a computer program, where the storage medium so configured causes a computer to operate in a specific and predefined manner to perform the functions described herein.

[0052] A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. The invention is defined by the following claims and their full scope and equivalents.

Claims

1. A method for attenuating wind noise in a signal, comprising:

- performing time-frequency transform on said signal to obtain transformed data;
- performing signal analysis on said transformed data to identify spectra dominated by wind noise;
- attenuating wind noise in said transformed data;
- constructing a time series from said transformed data.

2. The method of claim 1 wherein said step of performing signal analysis further comprises:

- analyzing features of a spectrum of said transformed data;
- assigning evidence weights based on said step of analyzing; and
- processing said evidence weights to determine the presence of wind noise.

3. The method of claim 2 wherein said step of analyzing further comprises:

- identifying peaks that have a Signal to Noise Ratio (SNR) exceeding a peak threshold as peaks not stemming from wind noise.

4. The method of claim 2 wherein said step of analyzing further comprises:

- identifying peaks in said spectrum that are sharper and narrower than a certain criteria as peaks stemming from a signal of interest.

5. The method of claim 4 wherein said step of identifying measures peak widths by taking the average difference between the highest point and its neighboring points on each side.

6. The method of claim 2 wherein said step of analyzing further comprises:

determining the stability of peaks by comparing peaks in the current spectra of said transformed data to peaks from previous spectra of said transformed data;

identifying stable peaks as peaks not stemming from wind noise.

7. The method of claim 2 wherein said step of analyzing further comprises:

determining the differences in phase and amplitudes of peaks from signals from a plurality of microphones;

identifying peaks whose phase and amplitude differences exceed a difference threshold and tagging said peaks as peaks stemming from wind noise.

8. The method of claim 1 wherein said step of attenuating wind noise further comprises:

suppressing portions of the spectra that are dominated by wind noise;

preserving portions that are dominated by a signal of interest.

9. The method of claim 8 further comprises:

generating a low-noise version of transformed data.

10. The method of claim 1, further comprising the steps of:

performing reconstruction of the signal by interpolation or extrapolation through the time or frequency regions that were masked by wind noise.

11. An apparatus for suppressing wind noise, comprising:

a time-frequency transform component configured to transform a time-based signal to frequency-based data;

a signal analyzer configured to identify spectra dominated by wind noise;

a wind noise attenuation component configured to minimize wind noise in said frequency-based using results obtained from said signal analyzer;

a time series synthesis component configured to construct a time-series based on said frequency-based data.

12. The apparatus of claim 11 wherein said signal analyzer is configured to:

analyze features of a spectrum of said frequency-based data;

assign evidence weights based on the result of analyzing said features;

process said evidence weights to determine the presence of wind noise.

13. The apparatus of claim 12 wherein said signal analyzer is configured to analyze said features by identifying peaks that have a Signal to Noise Ratio (SNR) exceeding a peak threshold as peaks not stemming from wind noise.

14. The apparatus of claim 12 wherein said signal analyzer is configured to analyze said features by identifying peaks in said spectrum that are sharper and narrower than a certain criteria as peaks stemming from a signal of interest.

15. The apparatus of claim 14 wherein said signal analyzer is configured to measure peak widths by taking the average difference between the highest point and its neighboring points on each side.

16. The apparatus of claim 12 wherein said signal analyzer is configured to analyze by:

determining the stability of peaks by comparing peaks in the current spectra of said frequency-based data to peaks from previous spectra of said frequency-based data;

identifying stable peaks as peaks not stemming from wind noise.

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17. The apparatus of claim 12 wherein said signal analyzer is configured to analyze by:

determining the differences in phase and amplitudes of peaks from signals from a plurality of microphones;

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identifying peaks whose phase and amplitude differences exceed a difference threshold and tagging said peaks as peaks stemming from wind noise.

18. The apparatus of claim 11 wherein said wind noise attenuation component is configured to attenuate wind noise by:

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suppressing portions of the spectra that are dominated by wind noise; preserving portions that are dominated by signal of interest.

19. The apparatus of claim 18 said wind noise attenuation component is configured to attenuate wind noise by generating a low-noise version of transformed data.

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20. The apparatus of claim 11, further comprising:

a reconstruction component configured to reconstruct the signal by interpolation or extrapolation through the time or frequency regions that were masked by wind noise.

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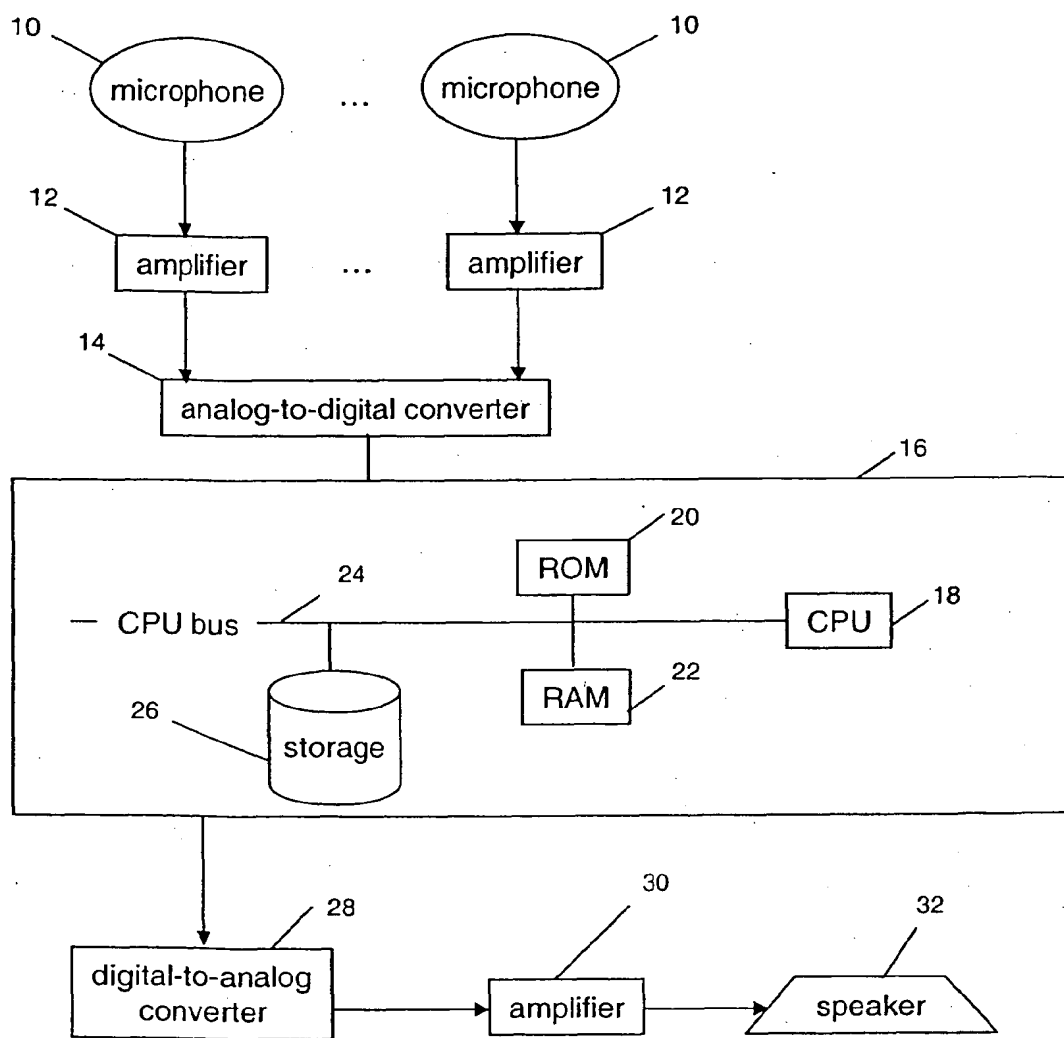
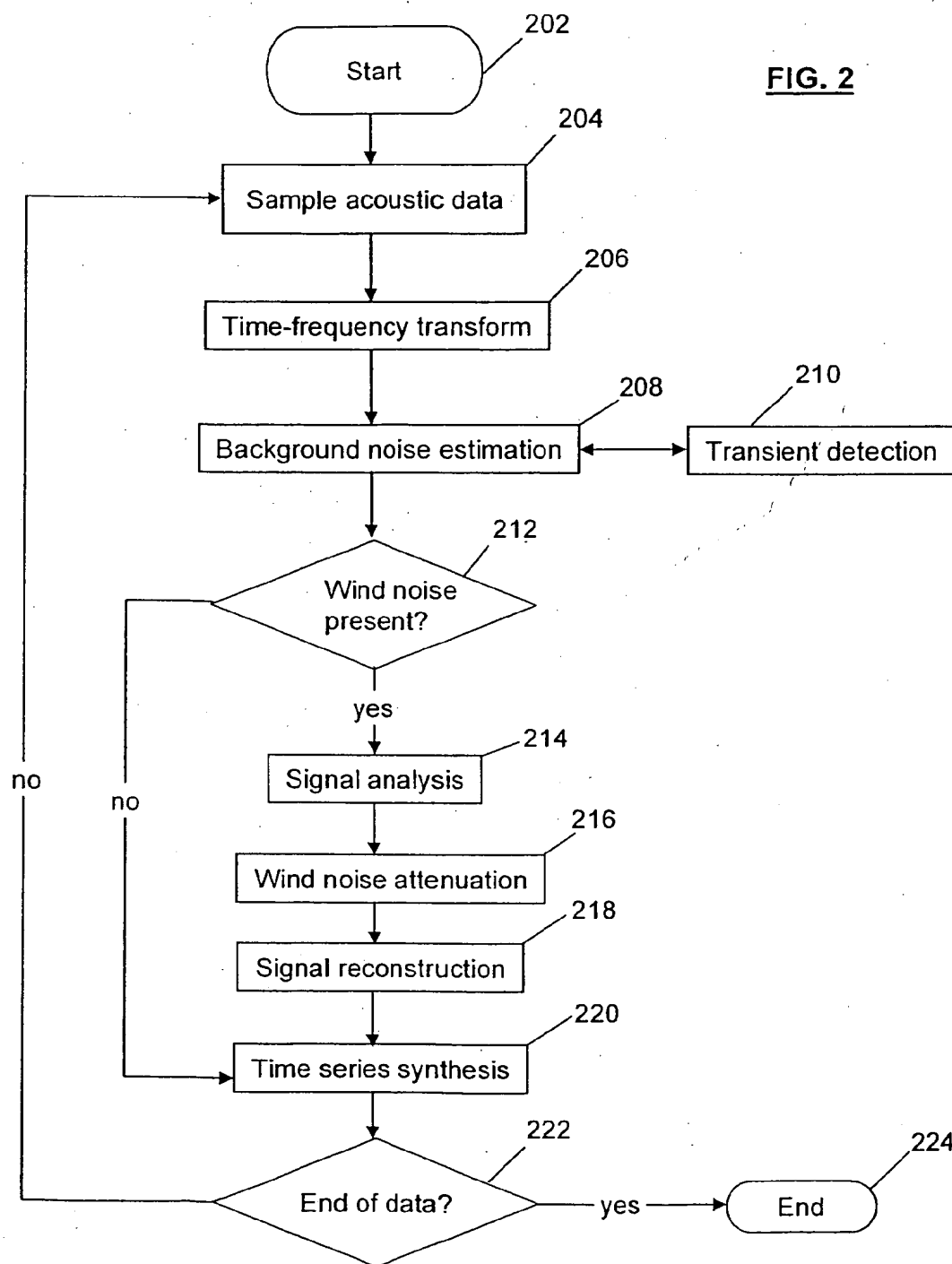


FIG. 1

FIG. 2



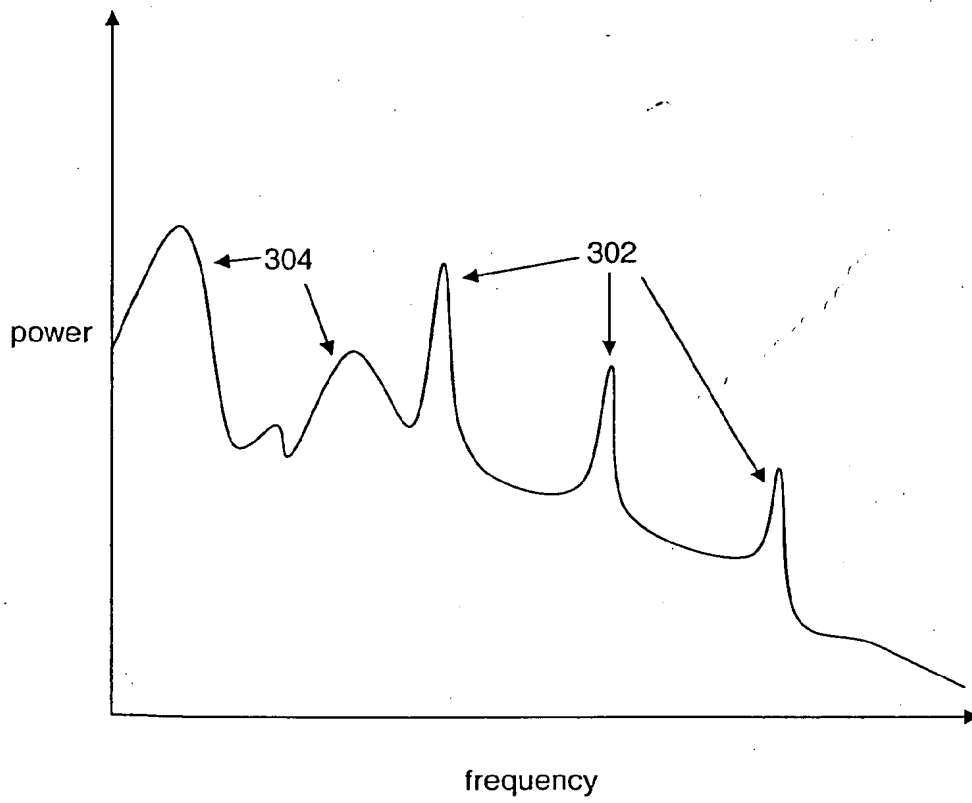


FIG. 3

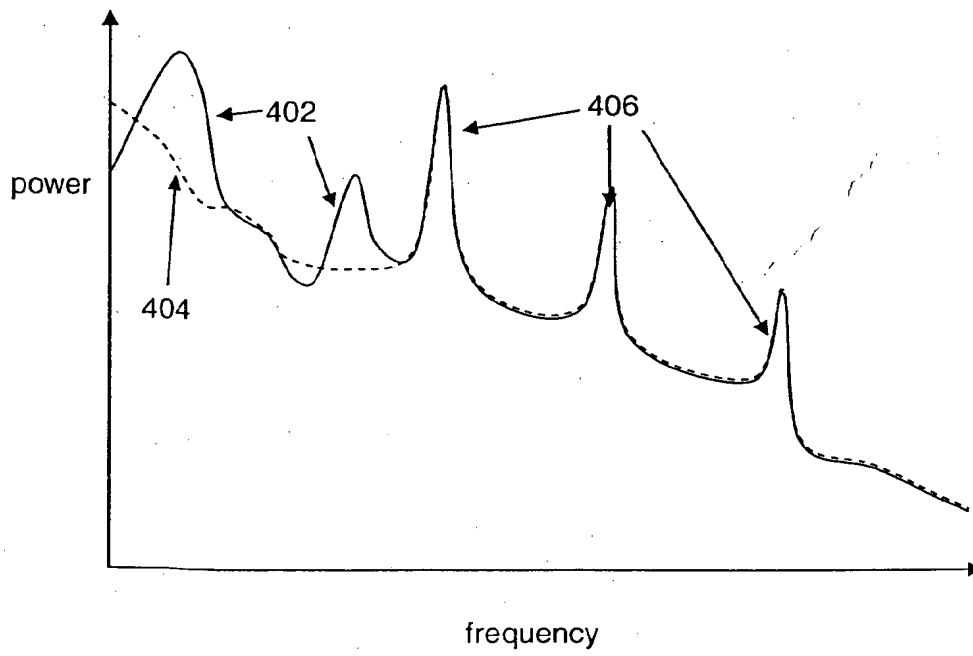


FIG. 4

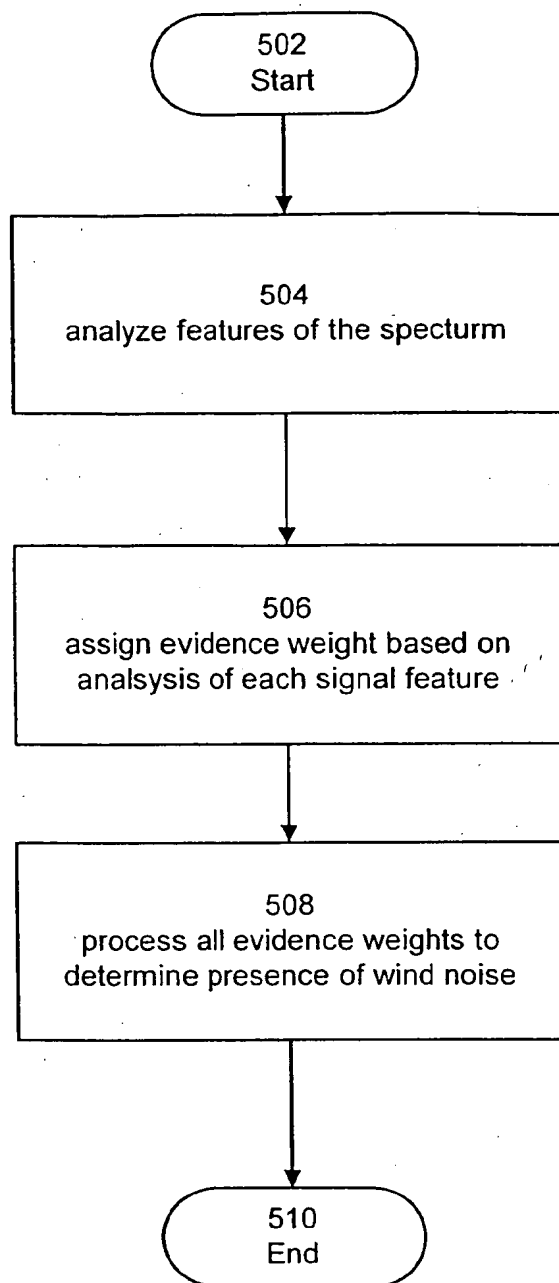
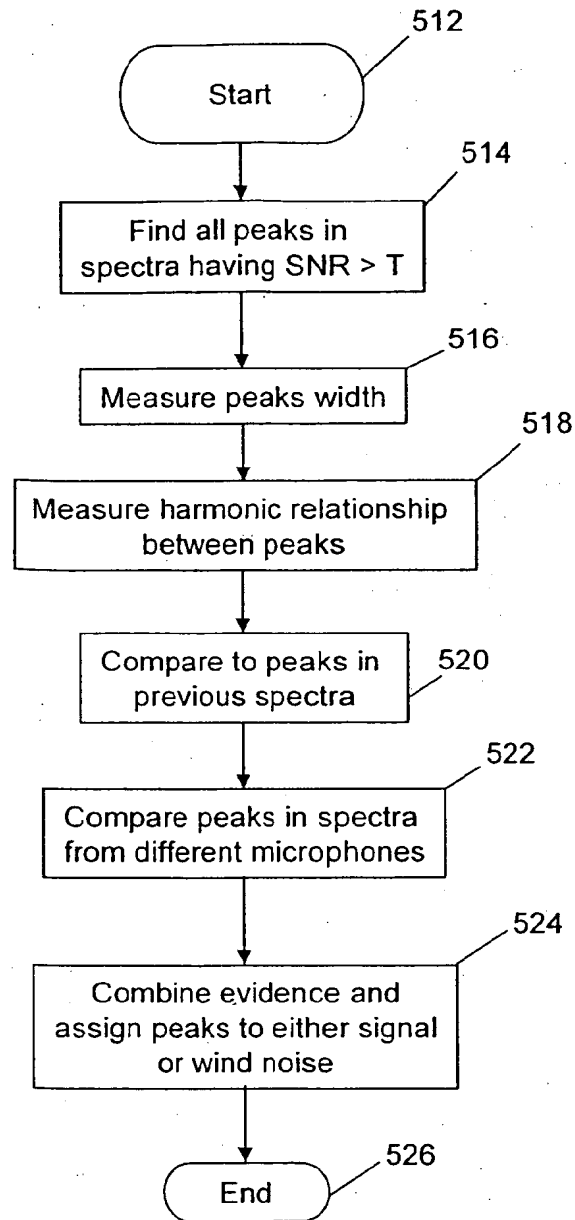


FIG. 5A

**FIG. 5B**

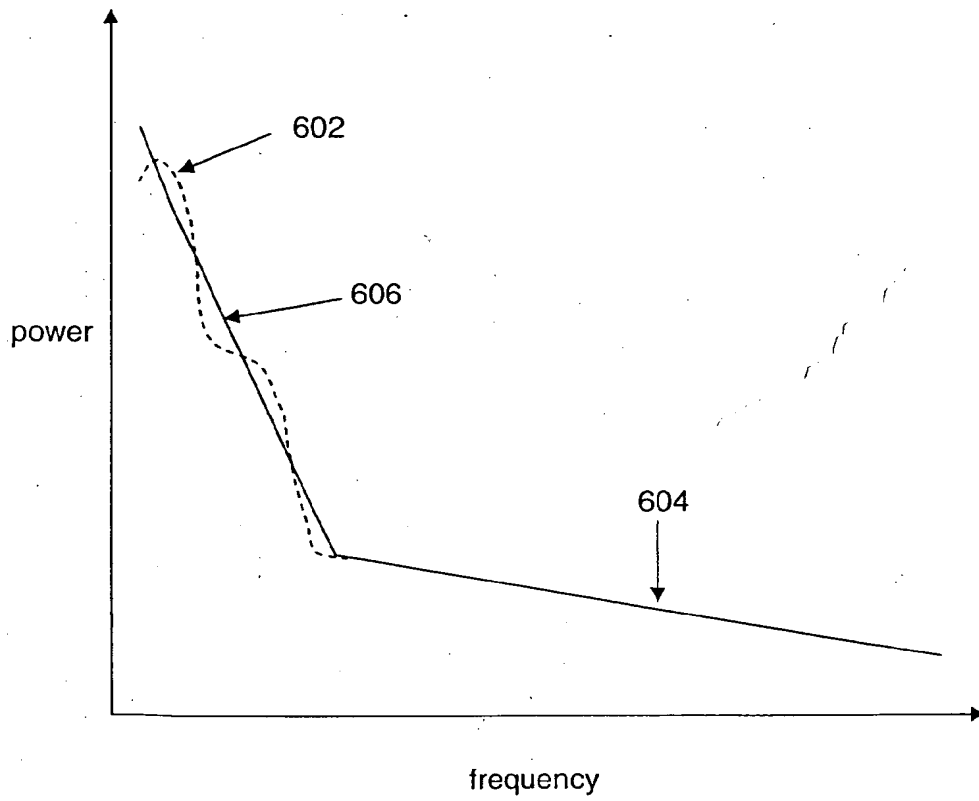


FIG. 6A

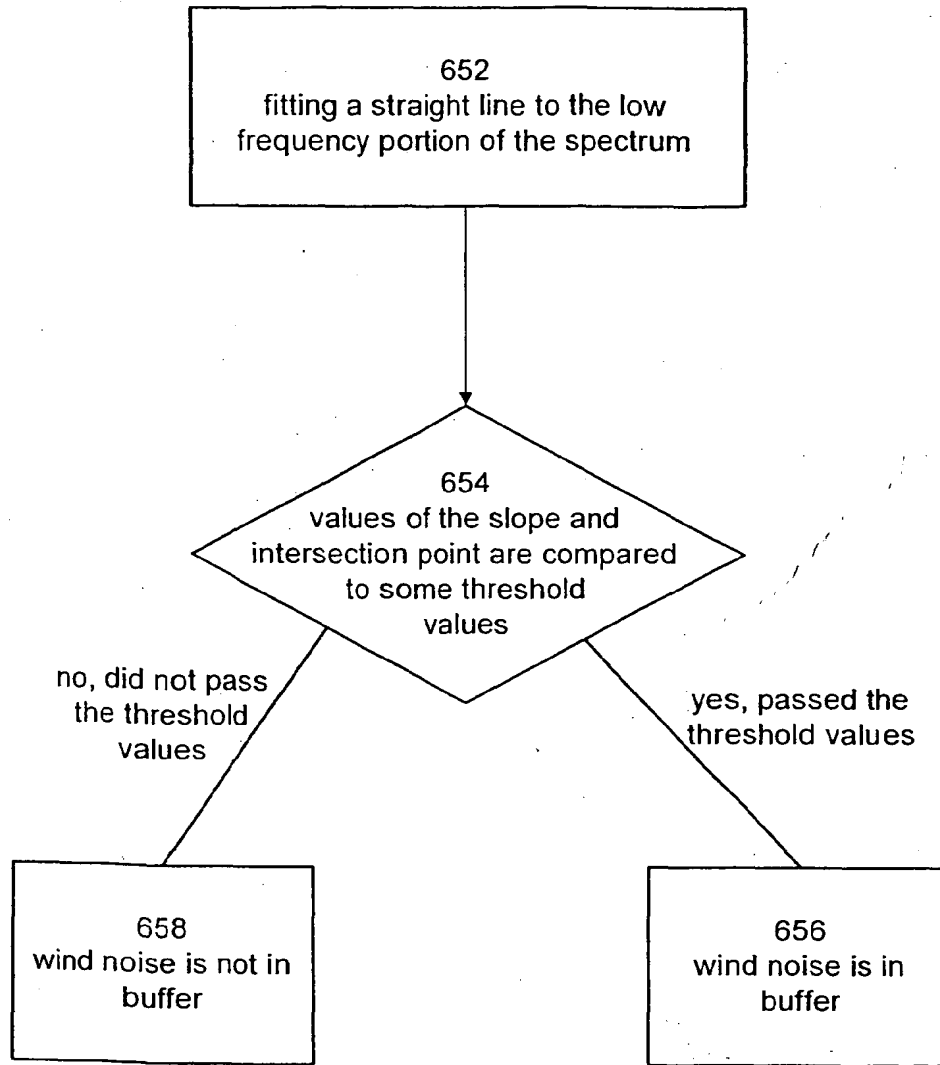


FIG. 6B

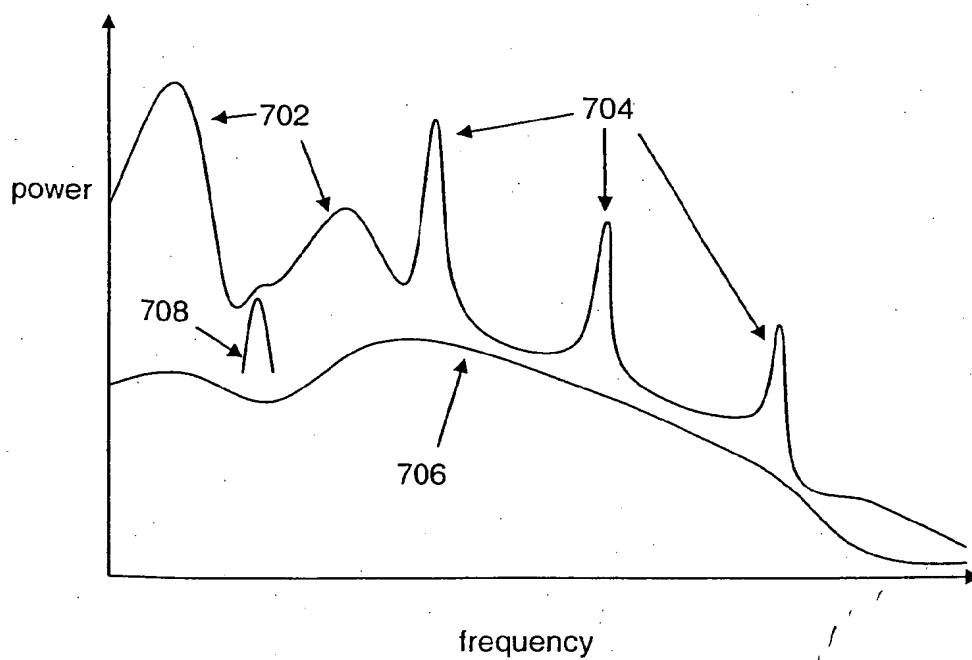
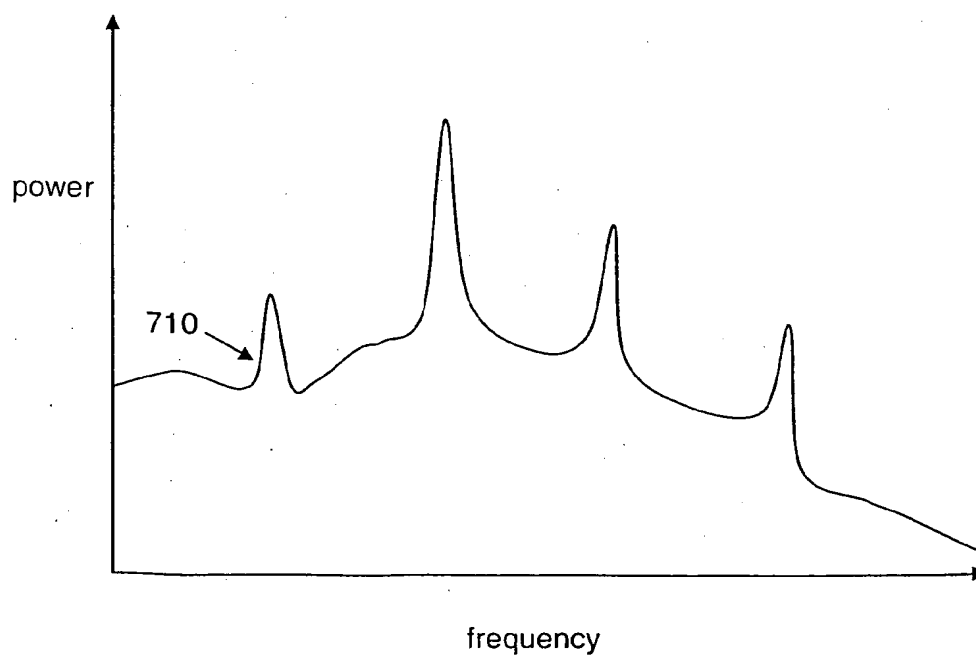


FIG. 7





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
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Place of search MUNICH		Date of completion of the search 3 May 2004	Examiner De Vos, L
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

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